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# Pipeline Blockage Unplugging and Locating Equipment

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**Abstract** – *This paper describes the development of a pulsed hydraulic system, specifically designed to unblock plugged piping. It uses the differences between the resonant vibrations of the fluid column and pipe walls to separate the blockage from the pipe wall, break it up, and clear the line. Using resonant frequencies, the system can stay below the design pressure of the system, preventing pipe failures from occurring, which is a major concern with DOE radioactive waste transfer lines.*

## I. INTRODUCTION

Occasionally pipes become clogged by solids, which must be dislodged to restore flow. Complex-wide, DOE has a need for a non-invasive method of clearing plugged radioactive waste transfer lines. A range of traditional techniques are currently used, despite their hazards. Over-pressurizing a line to attempt blockage removal is a common method, but this is often unsuccessful and undesirable. Other traditional invasive techniques include sewer snakes and water jetting. Since DOE waste transfer lines are usually buried, have few access connections, and contain radioactive material, inserting a snake or water jetting tool is not a good solution. While these methods can be effective, they create a significant problem with contamination cleanup and exposure of personnel to the pipe contents. In one case, a water jet hose lodged in the radioactive waste transfer line and had to be removed by dissolving it, which added a sticky, caustic substance to the system. Clearly a non-invasive technique is needed.

Non-invasive methods would be much easier to use in highly contaminated systems, pose fewer problems, reduces risk to personnel, and reduce the risk of equipment lodging in the piping. A non-invasive method for clearing blocked piping has emerged to service the petroleum industry. A pulsed high pressure method has been developed, which pulses the plug from alternate sides with a powerful hydraulic system. Refinery coker piping with over 50% blockages have been unplugged and cleared of caked powder using this type of system. Although effective, the high pressures used in the refinery would burst lower-pressure DOE waste transfer lines. Concepts from the refinery high pressure system were gleaned to create an effective low pressure method for DOE use.

It was noted that in the refinery system, vibration induced in the piping system from the pulses was doing

most of the work. In DOE's waste transfer pipes, the piping and blocking material can be vibrated at different frequencies extremely close to their resonant frequencies, dislodging the blockage without damaging the pipes and fittings. The equipment simultaneously activates a high-frequency vibration in the pipe wall and a lower-frequency vibration in the fluid column and blockage. Commercial equipment used in the refinery is not designed to control the pulse frequency, so a system with that capability needed to be designed and tested specifically for that purpose. This paper describes a resonant hydraulic system specifically designed to use that principle.

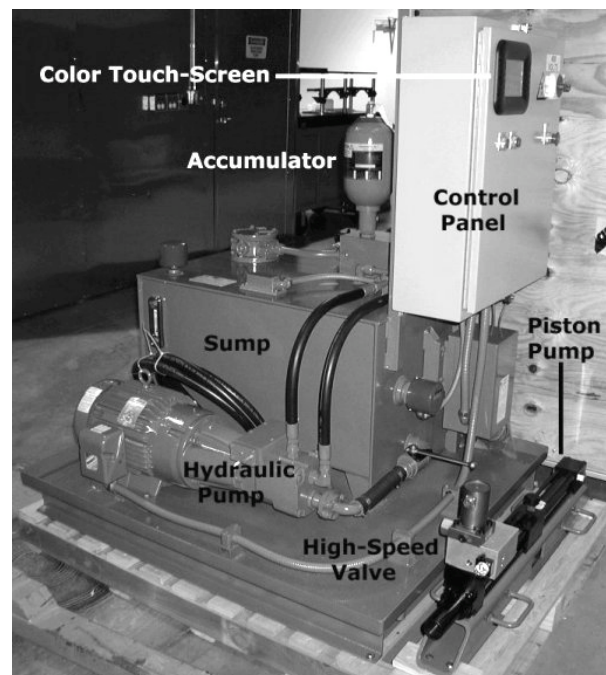


Fig. 1. Hydraulic Power Unit.

## II. EQUIPMENT DESCRIPTION

The system operates by hydraulically pulsing the fluid in the pipe using a reciprocating piston pump and check valves. The hydraulic pulses are directed into the pipe through a check valve, constantly pushing the blockage to move further down the inside of the pipe. This forces fluid in and around the blockage as it vibrates, lubricating it, and causing it to begin detaching from the pipe wall. Since the fluid resonance is dramatically different from the steel pipe wall resonance, the surfaces vibrate apart, dramatically helping to dislodge the blockage. As the blockage begins to move, it breaks apart and flows down the pipe.

Calculations were performed to determine the frequencies to target with the equipment. The average pipe run at the INEEL was estimated to be at least 30 meters in length, pumping water-based slurries. The resonance frequency and primary harmonics for the fluid column in that length of pipe are 24, 48, and 72 hertz. Longer pipe runs resonate at lower frequencies than these. The speed of sound in steel is considerably higher than in water, 5130m/s for steel and 1450 m/s in water, so the lengthwise resonant frequencies of the pipe walls are 3.54X higher, 85, 171, and 256 hertz. System sensors recorded data close to these numbers later on, validating these initial estimates. The specifications of the hydraulic system were sized to match, requiring speeds up to 30 hertz to hit the fundamental harmonic of the fluid.

The system consists of a number of hydraulic components, which can be seen on the hydraulic system diagram in the appendix and photographs of the equipment. The unit is skid mounted to allow portability to and from job sites, with a flexible jumper to facilitate making connections. The system uses a standard hydraulic pump, sump, and small accumulator to power the hydraulic side of the system. Hydraulic fluid from the pump is directed through a servo valve (the High Speed Valve in Figure 1) which is controlled by a programmable logic controller through a touch screen. The servo valve moves a hydraulic piston in and out to drive a slaved water cylinder to pump water pulses into the blocked pipe. This piston pump is called the Actuator Assembly on the hydraulic diagram in the appendix.

The water cylinder draws fresh water in through a check valve from a supply tank (a barrel in the test setup) and pulses it out through another check valve into the pipe. The plugged piping is protected from over-pressure by a relief valve, located on the water cylinder opposite the inlet check valve. The relief valve limits the maximum pulse pressure the piping is subjected to (300 psi in the test equipment). This fluid is directed back into the same barrel which supplies the piston pump with

water. A flexible hydraulic jumper is used to connect the unit to the plugged piping system. At the end of the flexible jumper is a hard-piped 'T' where the system's sensors are located, which is bolted onto the blocked pipe using a flange.

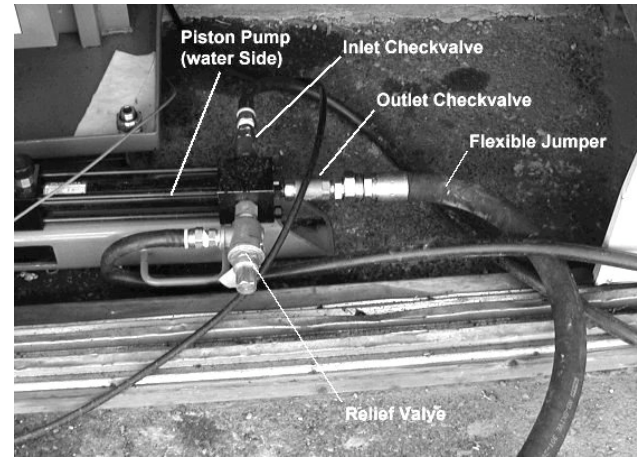


Fig. 2. Water-side plumbing.

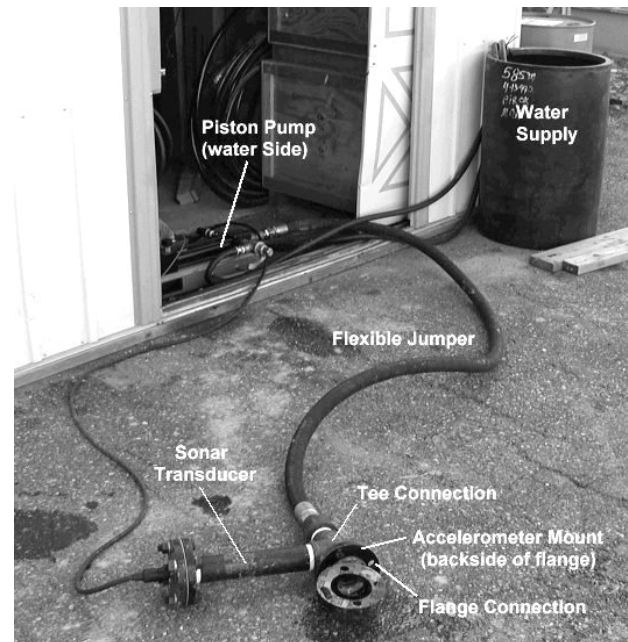


Fig. 3. Flexible Jumper and Sensors.

## III. SYSTEM CONTROLS

The unit is controlled through a programmable logic controller, which uses custom software to allow adjustments to the operation of the system. The frequencies, amplitudes, and timing of the cycles can be adjusted from the touch screen. The controller is currently set up with two alternating cycles; a cleaning

cycle and a flushing cycle. The cleaning cycle is designed to hydraulically water-hammer the blockage at the frequency and amplitude set by the operator, which should be set to match the resonance of the fluid in the piping. The cleaning cycle is followed by a flushing cycle, which pumps fluid smoothly into the system, to compress air voids and to pump water in and through the blockage. The cycles alternate until the hydraulic unit is stopped. Adjustments to the cycles can be made quickly and easily on the touch screen, then the hydraulic unit can be restarted to continue unblocking the pipe.

Data is collected off of the system's sensors and displayed on a separate computer. The software currently displays the pulses and pipe vibrations on the same plot, and allows the operator to perform FFT analysis on portions of the data to determine the vibrations induced in the fluid and pipe walls.

The system collects data on how both the fluid and pipe walls are vibrating from the sensors. Hydraulic pulses are sensed on a sonar transducer located in a branch 'T' just upstream of the connection to the blocked pipe. An accelerometer is mounted on the base of this hard-piped connection, which detects only pipe wall vibrations, allowing the two vibrational systems to be analyzed separately. The pipe walls vibrate at a much higher frequency (about 110 hz was one major peak) which can be seen on the accelerometer plot, plotted against the much higher amplitudes of the hydraulic pulses for reference. The fluid in the pipe vibrates at lower frequencies, down in the 10 to 30 hz range, dictated by the length of the pipe runs. By tuning the hydraulic pulses to match the fluid resonance, higher forces are applied to the blockage, making the system far more effective. Simply applying steady pressure has a much weaker effect on blockages, so much higher pressures have to be used in those systems. Using this information, the operator can tune the pulse frequency to the fluid resonance to increase the force applied to the blockage.

#### IV. DATA ACQUISITION SYSTEM

The data acquisition system consists of a personal computer (PC) equipped with a data acquisition (DAQ) card. The acquisition contains an application written using LabVIEW. The accelerometer and sonar (hydrophone) sensors are connected to the acquisition card through the DAQ card terminal block analog inputs.

The accelerometer is attached to the pipe wall and measures the instantaneous pipe movement magnitude. The hydrophone is suspended in the liquid and measures the instantaneous fluid compression magnitude. These values are stored in the data acquisition PC for analysis.

The data acquisition application has two modes: capture and analysis. In capture mode the application expends all of its resources to acquire data from the sensors attached to it. This amounts to 25K samples per second. When the "capture" is stopped this data is stored on disk and the system is placed in analysis mode.

In analysis mode the data is subjected to one of several different types of fast Fourier transforms (FFTs) depending upon which one the user has selected. The FFT analysis creates a logarithmic frequency spectrum graph. When a frequency is strong, it shows up as a spike in the graph. This is used to determine what frequencies are present in the pipe and fluid. The results as well as the original data are displayed on separate graphs for review. The data to be analyzed can be reduced by selecting a smaller region in the graph of the original data. This smaller subset of data is then what is subjected to the different FFTs. Reducing the data size and being able to isolate the analysis to areas of interest greatly enhance the effectiveness of the analysis. The application is also designed to allow other types of analysis depending upon the need for additional or different approaches. The code is structured to require minimal change to test out new algorithms or functions.

#### V. RESONANT PIPE BLOCKAGE LOCATION TECHNIQUE

The equipment may also be able to determine the location of a blockage by monitoring the resonant sound wave in the fluid. The resonant frequencies of the fluid column are a direct function of the distance from the hydraulic piston to the blockage. This feature has not been validated, since funding was cut short by DOE reorganization.

Piping filled with fluid acts as a waveguide for vibrations, and can be used to pinpoint blockage location. Since the vibration frequency is a function of tube length and the speed of sound in the fluid in the tube, the equipment described above causes a resonant sound wave in the fluid that is recorded by the low frequency, sonar transducer submerged in the fluid. The frequencies recorded are the fundamental frequency of the tube and a set of predictable harmonics. Analysis of the harmonics can yield the fundamental frequency, from which the length of the piping run to the blockage is directly calculated. Comparing this measurement to a drawing of the piping system, the location of the blockage can be pinpointed. Knowing the physical location may answer why the pipe became blocked by evaluating the pipe system configuration, and allows for more efficient excavation if the pipe has deteriorated in that location, or if resonant pulsing fails to remove the blockage.



## VI. MOCKUP AND TEST RESULTS

A pipe run was mocked up with 120 ft. of 2" schedule 40 carbon steel pipe. Each section was flanged for easy access, and two 90 degree elbows were used to add bends into the test setup. A 5 ft section of pipe was added onto the end, which was plugged solid with different combinations of silt, gravel, clay, and plant material to simulate a wide variety of blockages. Surrogate waste materials will eventually be used, if continued testing is funded. The hydraulic unit was placed in a small shed adjacent to the piping to keep it out of the winter weather, and connected to the mockup using the 10 ft. flexible hydraulic jumper. Makeup water was available from the main building next the test location, which was staged in a 55 gallon container. The data acquisition system PC was also staged in the shed, directly wired to the sensors mounted onto the flanged pipe tee on the end of the jumper.

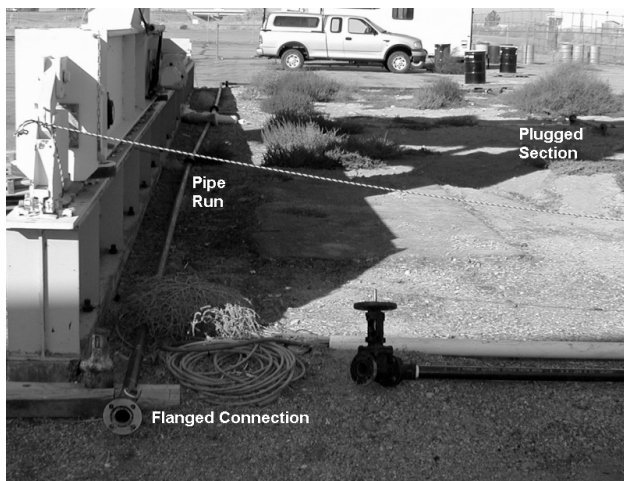


Fig. 5. Pipe Mockup.

Testing was successfully conducted on a wide variety of blockages. Even with the material packed solidly into all 5 feet of the end section, the pulsed hydraulic action was able to clear the blockage. Loosely packed plugs were the slowest, and would clear over five to ten minutes as flow gradually bypassed, disintegrated and flushed the blockage material away. Compacted plugs were more dramatic. Plugs with some amount of fibrous plant material would hold together and release in a burst as pressure in the system reached a critical point, usually within one minute of starting. An attempt was made before many of the test runs to fill the pipe completely with water to remove all air pockets, but this was not actually necessary. The compressed air pockets assisted in removing the blockages by expanding and continuing to push them down pipe as the plug would release.



Fig. 6. Plugged 5-foot section.

Adjustments to the frequency and amplitudes of the hydraulic system had a significant effect on the performance of the system. When the system was operated at or near resonance, it was much more effective than when it was pulsed much slower. Testing however, was cut short. Due to changes in the direction of the DOE Office of Science and Technology (OST) funding for all projects were cut off when they reorganized, so testing has not been completed. Work still needs to be performed to optimize the equipment settings, and very little work has been performed to validate the blockage location technique.

## VII. ADDITIONS

The system can also be augmented in a number of ways. It would be desirable to have a high-flow flushing pump added to the system. This would give the operator the capability of rapidly flushing the piping as soon as a blockage dislodges, taking advantage of the momentum of the surge as it breaks free. It would also be advantageous to add a simple pressure gage to the sensor 'T', so pressures and surges could be more readily seen by the operators. The gage would help the operators in seeing when the system has pressurized the piping on start up, or if the water cylinder is air-bound and needs to be primed.

The system can also be configured to augment a pumping system, to keep down-stream particulate in motion to prevent blockages before they start. This feature would continuously vibrate and monitor the fluid as it is pumped into a piping system. The hydraulic pulse-action would continuously agitate the fluid in the piping system, causing the piping to vibrate, and keeping the particulates moving. The solids in the fluid would not be given a chance to settle into a convenient location and build up until the pipe becomes plugged.

The system could also be configured to perform automatic blockage removal. In order to facilitate this, the system would require a feedback control loop based upon the frequencies being produced. A real-time frequency analyzer would be employed to determine the dominant frequencies present in both the pipe and the fluid. The system would then dynamically modify the piston duty cycle, vibration frequency, and the waveform

of the control signal to the piston to match the dominant modes. The system would not need to run continuously necessarily, unless a blockage was detected in the system. This would allow the system to be implemented as both a maintenance and active blockage removal system.

#### VIII. SUMMARY

Overall the performance of the system has been very satisfactory, clearing every silt blockage placed into the line. The basic concept of using resonance to increase the

effectiveness of the system has been proven, and greatly enhances the forces applied to clearing plugs. Additional work is needed to determine the optimum system settings, and to explore the concept of determining the location of the blockage using the resonant frequency of the pipe run. Demonstrations of the equipment were conducted for the end customer, the INEEL Tank Focus Area, who graciously extended funding to allow initial testing of the system after the DOE OST closed down their research and development branch.

# APPENDIX

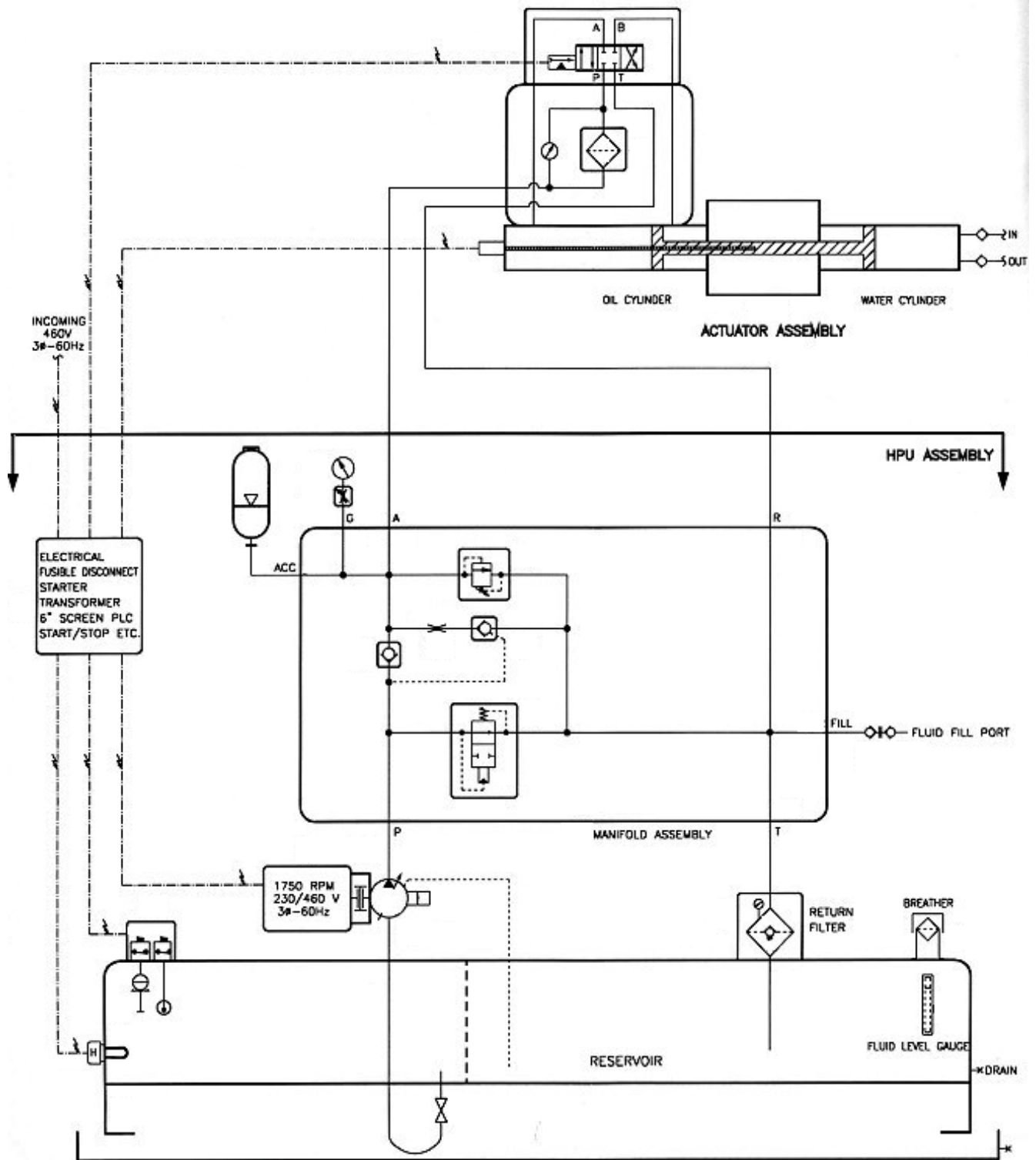


Fig. A-1. Hydraulic System Diagram.